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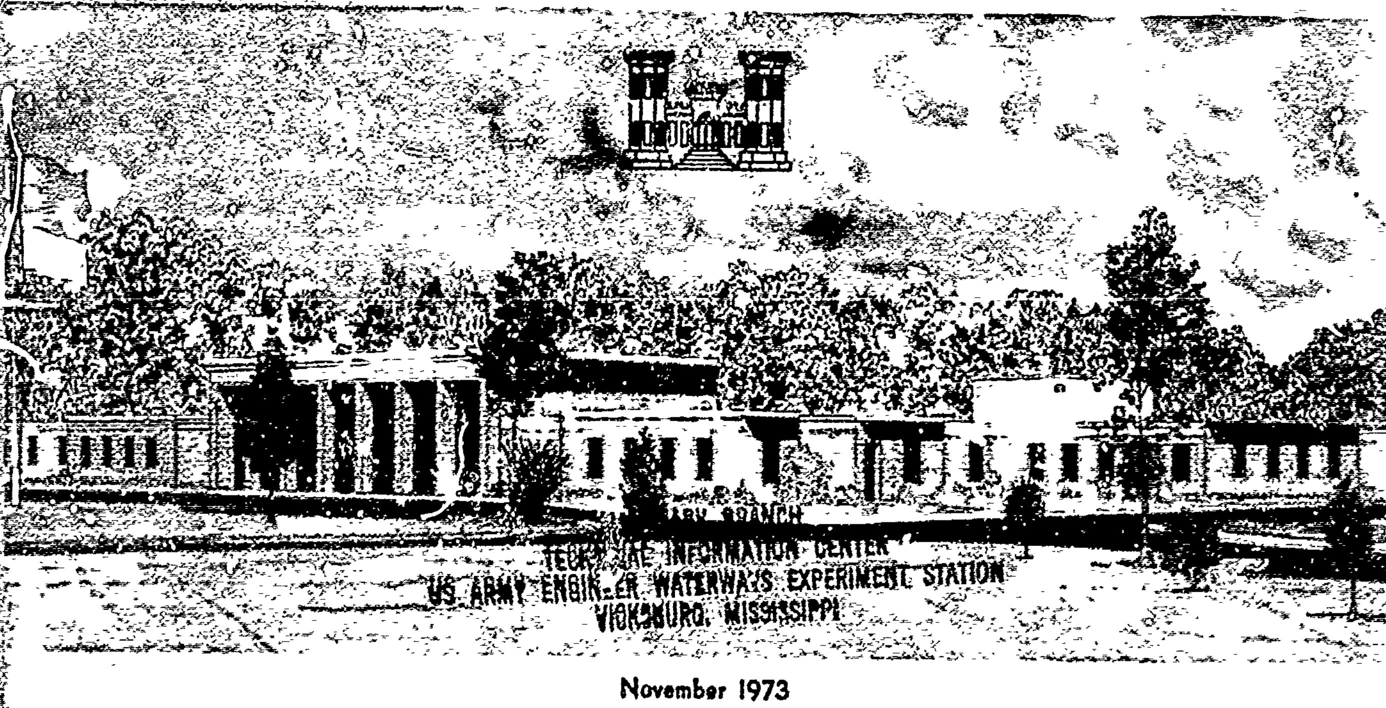
EXAMINATION OF CORES FROM FOUR HIGHWAY BRIDGES IN GEORGIA

by

K. Mather



November 1973

Sponsored by The Georgia Department of Transportation

Conducted by U. S. Army Engineer Waterways Experiment Station
Concrete Laboratory
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ARMY-MRC VICKSBURG MISS

FOREWORD

The work upon which this report is based was done at the Concrete Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the Georgia Department of Transportation. The specimens studied represented concrete made using coarse aggregates from two sources and fine aggregate from a third source that have been used on a number of civil works and military construction projects of the Corps of Engineers and are reported on in WES TM 6-370 as source No. 1 in area 32/81, source No. 5 in area 33/82, and source No. 3 in area 33/84. It was therefore concluded desirable to make copies of this report available to relevant Corps of Engineers offices. The cooperation of the Georgia Department of Transportation in allowing this to be done is appreciated. This is CTIAC Report No. 12.

The work was done and this report prepared by Mrs. Katharine Mather, Chief, Petrography and X-Ray Branch, Engineering Sciences Division (ESD), Concrete Laboratory (CL), under the general supervision of Mr. R. V. Tye, Jr., Chief, and Mr. Leonard Pepper, Acting Chief, ESD, and Mr. Bryant Mather, Chief, CL.

Directors of WES during the conduct of this work were BG Ernest D. Peixotto and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	by	To Obtain
inches	2.54	centimetres
miles (U. S. statute)	1.609344	kilometres
feet	0.3048	metres

SUMMARY

Six concrete cores from four structures built by the Department of Transportation, State of Georgia, were examined. Two of the structures were built in 1937, one in 1946, and one in 1947-48.

Three of the structures were built using high-alkali cement and one with a cement of average alkali content slightly above 0.60 percent. The coarse aggregate in three of the structures was granitic gneiss from one source; the coarse aggregate in the fourth was granitic gneiss from a second source. Evidence of alkali-silica reaction was present in all of the cores in the form of one or more of the following: gel reaction product; internal cracking in some coarse aggregate; and localized depletion of calcium hydroxide in cement paste adjoining some pieces of coarse aggregate. No constituent usually found to be alkali-silica reactive was present. Quartz, which has been associated with alkali-silica reaction on a very few previous occasions, and plagioclase feldspar, appeared to have been the reacting constituents.

EXAMINATION OF CORES FROM FOUR HIGHWAY BRIDGES IN GEORGIA

INTRODUCTION

1. When alkali-silica reaction, reaction between minor alkalies in portland cement and constituents of the coarse and fine aggregate, in portland cement concrete constructions is suspected as a cause of distress, several lines of evidence may be followed to verify or refute the suspicion. When the structure is examined, evidence of structural expansion may be found as an increase in the dimensions of part or all of the structure, usually accompanied by intersecting polygonal cracks. Closed expansion joints in hot weather are not necessarily evidence of expansion produced by alkali-silica reaction since thermal expansion of concrete in hot weather may close the joints. Gel exudations are sometimes recognized in the field but samples should be examined in the laboratory to verify the nature of the exuded material.

2. When cores from constructions are examined in the laboratory, the presence of gel in or on concrete provides unequivocal evidence of alkali-silica reaction in concrete containing siliceous aggregate.[1] Gel may also be found as small scattered bodies in concrete that does not show symptoms of distress. Other evidence of alkali-silica reaction that has produced distress in concrete has been described by L. S. Brown.[2] He has illustrated darkened rims at the outer borders of particles of crushed stone, internal cracks in such particles that narrow or terminate at the dark border, and peripheral cracking around the border of an aggregate particle inside the margin of the particle. McConnell et al.,[1] Mielenz,[3] and G. M. Idorn[4] have illustrated crack phenomena similar to

those found in some of the granite gneiss particles in the cores from the four structures in Georgia whose examination is described in this report.

3. The aggregate constituents that are expected to participate in alkali-silica reaction are opal, chalcedony, some cherts, cristobalite, tridymite, acid volcanic glass, rocks containing these constituents, and synthetic glasses as contaminants of aggregates. Under some circumstances other aggregates have been known to react in field concrete. These have included quartz,[5] quartzite,[5] varved argillite, and graywacke.[6] No references were found to alkali-silica reaction in which granite or granite gneiss were involved as the reactive constituents of the aggregate.

4. The background provided by C. C. Oleson[7] has been most valuable in the examination of these cores and in consideration of the problems that they pose.

SAMPLES AND TESTS

5. Samples. Six 4-inch*-diameter diamond-drilled cores from four bridges in Georgia were brought to the Concrete Laboratory, Waterways Experiment Station, by Mr. Ray Griggs on 9 July 1973. They are described in table 1.

6. Test Procedure. All of the cores were examined visually and using a stereomicroscope. The vertical core from near Soperton (GDOT-1), the core from near Millen (GDOT-3), and one core from Springfield (GDOT-4) had been sliced at the laboratory of the Division of Materials and Tests of the Georgia Department of Transportation. Drilled and sawed surfaces and broken surfaces were examined. Finely ground surfaces of cores GDOT-2, GDOT-3, GDOT-4, and GDOT-5 were prepared and examined. Thin sections of

* A table of factors for converting British units of measurement to metric units is presented on page vii.

all six cores were prepared and examined. Immersion mounts of deposits from GDOT-1, 2, 3, 4, 5, and 6 were examined using a polarizing microscope. The coarse aggregate particles on sawed and sawed and finely ground surfaces were counted using a stereomicroscope and their internal cracks were recorded. Internally cracked coarse aggregate particles and crack-free aggregate particles from GDOT-2 were marked on a sawed surface. These pieces were removed from the concrete by sawing and chipping, were ground to pass the No. 325 sieve, and were examined by X-ray diffraction.

RESULTS

7. Examination of cores GDOT-1 and 2 from bridge four miles northwest of Soperton. The coarse aggregate in all six cores was granite gneiss and the fine aggregate was natural sand. On both of the Soperton cores what appeared to be rims in the coarse aggregate were prominent on recently fractured and freshly fractured surfaces. The vertical core, GDOT-1, consisted of an upper section 4-1/2-inches long which was received in six pieces. Two or three curving vertical cracks with thick deposits of secondary yellowish brown (10 YR 4/2)[8] calcite on their surfaces divided the larger pieces of the upper section. The original upper surface was missing. On the lower surface of the lower section one piece of coarse aggregate appeared to be surrounded by gel-soaked paste. The horizontal core (GDOT-2) revealed three partially gel-filled voids on the inner surface. The outer surface was weathered and cracked in a network of narrow cracks forming a pattern of polygons ranging from 1 to 1-1/2 in. in maximum dimension. When finely ground surfaces of the outer section of GDOT-2 were examined it was seen that the outer face of the core and

some of the concrete to depths of about 1/8 to 1/2 in. had been altered with a color change from light gray (N 7) to yellowish gray and grayish yellow (5 Y 7/2 and 5 Y 8/4). The coarse aggregate appeared to be of 1 in. maximum size and was not very abundant. Mortar made up more than 50 percent of the sawed surface; voids up to 3/16 in. in diameter were present but not abundant; the concrete did not appear to be air-entrained. Rims along parts of the border of cross sections of coarse aggregate particles were present. Several of the coarse aggregate particles were bordered externally by fine cracks filled with a white silkily lustrous substance; several similar cracks ran from piece to piece of coarse aggregate or passed through the paste running around grains of fine aggregate near the inner end of the core. In thin section the crack fillings were identified as ettringite. Core GDOT-2 was sawed parallel to the long axis. Two thin sections were made using areas on a slice parallel to the longitudinal saw cut, one 2-1/8 in. inside the surface of the wall and the other 2-1/2 in. inside the surface. The other half of the core was sawed into two pieces parallel to the longitudinal axis; two of those surfaces were finely ground. The sawed and ground surfaces are illustrated in photographs 1 through 4. Internal cracking in the coarse aggregate is shown in photographs 2 and 3 and another piece with internal cracks and an associated gel pocket is shown in photograph 4. A partial gel lining was found in an entrapped air void on one face of one of the longitudinal quarters. The gel lining was thin, clear, and cracked into small fragments with upturned edges.

8. An immersion mount of material resembling gel taken from one of the three partially gel-filled voids on the inner end of the horizontal core proved to be strained gel with a refractive index somewhat above 1.460.

9. The compositions of six reacted and four unreacted pieces of coarse aggregate are shown in table 2.

10. Thin sections of GDOT-1 and GDOT-2. One thin section of GDOT-1, the vertical core, was taken adjoining a finished surface, which proved to be carbonated but not to an unusual depth for concrete 37 years old. Cracks in the mortar and bordering coarse aggregate were common; most were filled with ettringite. Calcium hydroxide was abundant and in general normally distributed although a few small areas of mortar were seen in which the calcium hydroxide appeared to have been dissolved from the original crystals and reprecipitated in very small crystals. Parts of coarse aggregate particles in section GDOT-1-2 had been lost during sectioning from parts of the thin section at locations not near the edges of the section. The edges are usually the regions from which parts of coarse aggregate particles are likely to be lost in sectioning normal concrete. Losses of some of the interior of coarse aggregate or of a corner with a small area of adjoining mortar have been observed in concrete in which more conspicuous evidence of alkali-silica reaction has been recognized.

11. Cracks passing through some fine aggregate particles penetrate the cement paste for relatively short distances. Cracks pass from inside coarse aggregate particles into the mortar and cracks in the mortar are commonly filled with ettringite and, more rarely, with gel. Sometimes

there was no filling or it was removed in sectioning. The cracking is extensive on the scale of a thin section blank 7/8 in. wide and 1-1/2 in. long (22 mm by 38 mm). It is less extensive on the scale of a finely ground surface examined at 7 to 30X with a stereomicroscope than was the case with GDOT-3. The cracks are minutely sinuous, and pass from the border of a fine aggregate particle to the nearest border of a fine aggregate particle that lies in the general direction of the crack. Much of the ettringite fillings consists of needle-like crystals lying across the crack at about 90 degrees to the crack wall, but there are also tufts radiating from one wall and some needles lying subparallel to the crack direction. It is common to find cracks bordering coarse aggregate particles and then running into the mortar.

12. One thin section from the vertical core from the bridge near Soperton contained strained gel and the paste adjoining this area and a particle of coarse aggregate was almost free of calcium hydroxide. Calcium hydroxide crystals are usually scattered through the paste of mature concrete and tend to grow in narrow openings along the borders of coarse and fine aggregate. Areas in thin sections of normal thickness which do not contain calcium hydroxide are usually associated with an unusual chemical reaction such as alkali-silica reaction or an alkali-carbonate reaction.

13. The thin sections of the horizontal core from Soperton were like those from the vertical core in containing frequent cracks, some fairly wide, with ettringite fillings. The first section (GDOT-2-1) contained a little gel; the second contained gel-soaked paste, darkened

and depleted in calcium hydroxide. The texture was unusual in parts of the section in that the calcium hydroxide appeared to have been dissolved and reprecipitated in minute crystals.

14. Examination of GDOT-3, core from bridge over Ogeechee River 2 miles south of Millen. Mr. Griggs's photographs of end posts and posts and handrails of Bridge A show extensive polygonal cracking in the end posts and adjoining sidewalks and curbs. The core was drilled in late May 1973 vertically through a curb; one intact section 6 in. long and three slices fitting to the intact section were received. The broken lower surface of the lowest slice contained several small areas of gel in pockets adjoining rimmed coarse aggregate particles and one rounded quartz or quartzite particle of fine aggregate; gel extracted from one pocket was examined as an immersion mount in an index liquid with a refractive index of 1.460. The gel was brownish in plane light, with the refractive index above 1.460, and with crossed polarizers showed a few minute slightly birefringent areas; thin fragments were not birefringent.

15. Photograph 5 shows a sawed and ground longitudinal section through the upper part of the core. Two open wide cracks run from the finished surface at the top of the photograph for relatively short distances into the core. In the relatively large mortar area about 4 in. below the top surface three vertically trending filled cracks can be seen. They are part ot an extensive crack system that is traced in photograph 6. The crack near the middle of the top surface ran all the way across the top of the core, while the crack at the upper right was

present but inconspicuous on the top surface. If one considers the crack system in photographs 5 and 6, on the surface, and in the thin sections it appears that elongation parallel to the long axis of the core and widening normal to the long axis of the core have both taken place. Some of the crack fillings in the paste and in a few cracked aggregate particles consist in part of alkali-silica reaction gel but a far greater part of the preserved fillings in the thin sections consist of ettringite. Presumably the ettringite filled the cracks that it occupies when the cracks were open and relatively empty, thus when the concrete as a whole was in an expanded condition. However, the concrete cannot be assumed to have been in the most expanded condition that it ever achieved, if it is assumed that ettringite crack-fillings bordering coarse aggregate, except those along undersides as cast, formed in space made vacant by shrinkage of the aggregate after it had been in the most expanded condition. It is not believed that there was an external source of sulfate to react with tricalcium aluminate but rather that the ettringite is that characteristic of fairly advanced concrete deterioration, and represents the original sulfate and tricalcium aluminate contents of the cement redeposited outside of the mortar in open space produced in part by early subsidence below coarse aggregate and in part by cracking caused by alkali-silica reaction.

16. Examination of thin sections GDOT-3-1 and 3-2. Both thin sections showed paste bordering coarse aggregate depleted in calcium hydroxide. The second thin section showed some gel-soaked paste along the boundary of one coarse aggregate particle.

17. <u>Examination of GDOT-4 and GDOT-5, from underpass 2 miles northwest of Springfield, Ga.</u> Photographs of this structure show extensive cracking of the north side of the southwest wall; vertically trending open cracks and a network of roughly horizontal and vertical fine cracks are present. The south side of the southwest wall shows a similar network and one vertically trending crack that is wide open at the top. The cores were taken horizontally on the north side of the southwest wall. The outer section of each was sawed longitudinally. An open wide crack on the outer formed surface of GDOT-4 could be traced 2-3/8 in. down the side. An open crack on the formed surface of GDOT-5 ran to depths of 5/8 to 7/8 in. depending on where it was measured. One longitudinal sawed surface of the outer section of GDOT-4 was finely ground; another surface produced by sawing a slice from which thin section blanks were taken was also examined. The color of the mortar ranged between white (N 9) and very light gray (N 8); parts of the mortar on both surfaces were fragile and easily broken; on the finely ground surface irregularly shaped areas tore out or were originally missing. In the thin sections of GDOT-4 a similar phenomenon existed on a smaller scale; areas of irregular shape scattered in the mortar were filled with ettringite, but parts of the larger areas that may once have been filled with ettringite have been torn out leaving irregular voids with ettringite filling along the boundaries. It is now impossible to tell whether or not the filling was originally complete. Both vertically trending and horizontally trending cracks filled with ettringite and underside voids filled with ettringite were present but there are fewer cracks filled with ettringite in these thin sections than in the thin sections of cores from the underpass northwest of Soperton.

18. Part of thin section GDOT-4-2 appears to have a normal texture for cement paste in a concrete of fairly high water-cement ratio; measurements of 18 calcium hydroxide crystals gave an average maximum dimension of 77 μm (range from 13.8 to 161.4 μm) but parts of the thin section contained abundant calcium hydroxide crystals that measured about 2 μm or less although a few crystals with maximum dimensions up to 60 μm were present. It is thought that this substantial reduction in maximum dimension of calcium hydroxide was the result of solution and reprecipitation as moisture moved through the wall from the embankment to the free surface of the concrete. No unequivocal evidence of alkali-silica reaction was recognized in the thin sections of GDOT-4; thin section GDOT-5-1 contained cracks between two quartz grains and the adjoining cement paste that appear to be filled with gel that is isotropic and of low refractive index. A similar phenomenon was found in GDOT-5-2.

19. Piece 2B of GDOT-4 contained a void about 1/8 in. in maximum dimension with a thick white opaque lining that had cracked in a way that suggested shrinkage during drying. Immersion mounts of the filling contained some calcium carbonate but more of a partly crystalline mixture that was probably altered gel. It contained some small crystallized areas of low birefringence and some isotropic areas of refractive index slightly above 1.460.

20. Photographs 7 through 9 show ground surfaces of GDOT-4 and 5. By comparison with the cores from near Soperton, near Millen, and near Piney Bluff, less cracking can be seen when the cores are examined. On ground sawed surfaces examined at magnifications of 13X and 30X internal

cracks in coarse aggregate and in at least two fine aggregate particles in the larger sieve sizes were recognized. The two cases in which cracks were seen in fine aggregate included one in which it would have been impossible for a particle so thoroughly cracked to have survived as a single particle if it had been so cracked when it was mixed in concrete. The same kind of argument applies to coarse aggregate particles such as the one in the left center of photograph 7 and the particle in the top right center of photograph 9; neither would have survived mixing in concrete in one piece if the concrete had been mixed with the particle in the condition in which it now is.

21. Examination of core GDOT-6 from near Piney Bluff. This horizontal core was taken from a wingwall in a bridge built in 1947-48 over the Altamaha River using crushed granite gneiss from Stockbridge, Ga., and local sand with high-alkali cement J. Two open cracks were visible on the patched exterior face of the core; the part of the patch that once was present on the exterior of the core was missing when the core was received. Three conspicuous gel-filled voids were seen on the inner end of the core and several others were visible when the core was examined using a stereomicroscope. Internal cracks were found in 21 percent of the coarse aggregate particles on a longitudinal surface sawed in the outer section of the core.

22. The coarse aggregate from Stockbridge in this core differed from the Camak coarse aggregate in being more variable in composition from particle to particle, and in containing less biotite and more quartz

than the Camak coarse aggregate. Some pieces on the sawed surface contained no dark minerals and appeared to consist almost entirely of quartz; others contained perhaps 5 percent of biotite in scattered flakes.

23. Cracks filled with ettringite were common along the outer borders of coarse aggregate particles on the sawed surface and some small voids filled with ettringite were present. In one of the thin sections gel was visible along the edge of a coarse aggregate particle and the adjoining paste was depleted in coarse aggregate; some gel-soaked paste with a little secondary calcium carbonate was present along the edge of the same particle as well as a crack filled with ettringite. There was, however, less ettringite than was found in the thin sections of cores from the underpasses near Soperton and Springfield.

DISCUSSION AND CONCLUSIONS

24. Summary. The conditions of the cores from the four structures are summarized in table 3. Although the underpass at Springfield contained cement H[7] with an average alkali content, expressed as Na_2O, of 0.62 percent while the other three contained cement J[7] with an average alkali content, expressed as Na_2O, of 1.02, the cores from the underpass near Springfield contained evidence of alkali-silica reaction (tables 3 and 4). The cores from the other three structures contained more evidence of alkali-silica reaction in terms of more abundant gel in the cores from the bridges near Millen and Piney Bluff, and more extensive internal cracking in the coarse aggregate in cores from the bridge near Millen and the underpass near Soperton.

25. Coarse aggregate from the quarry at Camak has been tested by the South Atlantic Division Laboratory of the Corps of Engineers at

Marietta, Ga., and Test Data, Concrete Aggregates in Continental United States[9] contains two sets of test results, from 1949 and 1969. Some of them are quoted below:

	1949	1969
Specific gravity	2.67	2.68
Absorption, percent	0.4	0.3
DFE_{300} of concrete containing coarse and fine aggregate from Camak	62	--
of concrete containing Camak coarse aggregate and Eden fine aggregate	--	64
Quick chemical test Sc	22	26
Rc	27	25
Loss in the Los Angeles abrasion test, grading A, percent	36.5	30

The petrographic description of the 1949 sample reports that it was porphyritic granite gneiss while the description of the 1969 sample says that it was 94 percent porphyritic granite gneiss and 6 percent diabase. It seems that the product of the quarry was fairly consistent between 1949 and 1969 and results of both sets of tests show that it had a relatively low loss in the Los Angeles abrasion test. If it is assumed that the aggregate from this quarry used in the structures built in 1937 and 1946 was like that tested in 1949 and 1969, it is hard to believe that the coarse aggregate as it was used contained the proportions of particles with internal cracks that are now found in the core from the underpass near Soperton and the bridge near Millen. This argument cannot be made with such force about the coarse aggregate from Stockbridge which has also been tested by the South Atlantic Division Laboratory. Two sets of results are compared below:

	November 1948	August 1966
Specific gravity	2.62	2.62
Absorption, percent	0.4	0.3
DFE_{300} of concrete containing Stockbridge coarse and fine aggregate	34	--
Quick chemical test Sc	20	--
Rc	8	--
of fine aggregate Sc	--	14
Rc	--	40
Loss in the Los Angeles abrasion test, grading A, percent	42.7	43

In the petrographic description made in 1948 the rock was classified as granite gneiss.

26. During the examination of the cores and the thin sections made from them a search was made for constituents known to be reactive with the minor alkalies of portland cement. A few coarse aggregate particles in a few thin sections appeared to contain narrow veins of chalcedony but where one such vein was in contact with cement paste there was no evidence of alkali-silica reaction. One piece of fibrous chalcedony in the fine aggregate in one thin section did not show evidence of alkali-silica reaction. Photographs 1 through 8 show internal cracks in the feldspar and quartz that were major constituents of the coarse aggregate; where the parallel traces of feldspar twinning appear to be continuous across the crack, as in the long crack shown in photograph 2, and the feldspar is unusually fragile as it was in the piece of coarse aggregate shown in that photograph it is hard to avoid the suspicion that the feldspar reacted. Photographs 3, 4, and 7 indicate that quartz also reacted. The reaction of quartz has been encountered before[5] and the possibility of such reaction has been discussed[10] with the suggestion that the

possibility of reaction was increased when the quartz was strained. Quartz in the coarse aggregate from Camak and Stockbridge has been strained but not to a greater degree than the quartz in many rocks in the Piedmont and the Appalachians; greater strain is known in metamorphic quartzites from the Blue Ridge. If strain during dynamic metamorphism were the only factor involved in creating the circumstances that render quartz capable of alkali-silica reaction in concrete, and if alkali-silica reaction were generally possible in quartz with cements containing 0.62 to 0.70 total alkali as Na_2O, alkali-silica reaction should be much more widely distributed in structures built with coastal plain and Piedmont gravels and granite gneisses from Southern New York State through Georgia, because most of the quartz in these aggregates shows some strain.

27. To summarize the conditions shown in the cores from the four bridges:

a. All four groups of cores exhibit evidence of alkali-silica reaction, in that gel was found in at least one core from each structure. Gel in the cores from the bridge near Springfield was sparse and sometimes extensively altered.

b. The coarse aggregate in all four groups of cores exhibited some internal cracks (table 3). Several exhibited partial peripheral cracks formed near the outer edge of the coarse aggregate and following its boundary, separating the particle into a rim bonded to the adjoining mortar and a central core; this kind of crack is illustrated in the large particle at the lower right about 1-1/8 in. above the bottom and the same distance in from the right margin of photograph 5; the same particle is also shown in photograph 6. The composition of six apparently reacted it is doubted that calcium aluminate hydrates with less sulfate than ettringite and with no sulfate would be present.

e. Although evidence of alkali-silica reaction and accompanying cracking in the concrete is present in the cores from all four structures, the evidence is much less abundant in terms of amount of gel, depletion of calcium hydroxide near reacted coarse aggregate particles as seen in thin section, softening of reacted coarse aggregate, development of peripheral and internal cracks in coarse aggregate, than was the case in the concrete from Tuscaloosa Lock when it was 10 to 12 years old, or of cores from a highway bridge in Oregon when they were 24 years old. Tuscaloosa Lock is probably the best comparison since it is located in a climate similar to the coastal plain of Georgia; all of the symptoms of alkali-silica reaction were much more advanced when the lock was half the age of the youngest of these four structures. Cracks in the Tuscaloosa Lock were of concern when it was cored in 1949 and are still of concern 24 years later, but the structure is still in service, although some repairs have been made.

28. The coarse aggregate from Camak did not appear to be reactive as judged by results of quick chemical tests (ASTM Designation C 289) made at the laboratories of the Portland Cement Association[7] or the South Atlantic Division Laboratory of the Corps of Engineers. On the basis of the composition as indicated by thin sections, and X-ray diffraction of ten coarse aggregate particles from GDOT-2, we would not have expected it to be alkali-silica reactive and neither did the petrographers at the South Atlantic Division Laboratory (SADL). The coarse aggregate from Stockbridge and the Eden sand were not reactive as judged by the

results of quick chemical tests made at the SADL. Although the quick chemical test is only one of three approaches to determining whether an aggregate is capable of alkali-silica reaction that are available in part 10 of the ASTM Standards, when its results apparently agree with petrographic information on the aggregate as is the case with the Stockbridge and Camak aggregate, it is surprising to find that these aggregates have been capable of reaction.

29. Cement specifications of the Georgia Department of Transportation. It is understood that after alkali-silica reaction had been detected in highway structures containing high alkali cements and gravels from several sources, the Georgia Department of Transportation specified cement containing not more than 0.60 percent total alkali expressed as Na_2O. The limit was not in force when these four structures were built, and the alkali contents of the cements used in these structures were not determined when cement was being shipped to build them. It is known that cement J was a high alkali cement containing about 1.00 percent total alkali expressed as Na_2O in the times when three structures containing it were being built.[7] Cement H apparently had a lower alkali content but ranged up to 0.70 total alkali as Na_2O.[7] Since the alkali content of cement H was not being determined while the underpass near Springfield was being built, the alkali content of the cement in the underpass is not known except insofar as alkali contents determined in 1936-37 are available. There is no known reason for believing in an external source of alkali. The relatively restricted development of symptoms of alkali-silica reaction in the cores from the underpass near Springfield as compared with the condition of the

cores of the other three structures appear to support the evidence that less alkali was available.

30. The limit of 0.60 percent total alkali expressed as Na_2O was first specified in California and later adopted by several other states, the Bureau of Reclamation, and the Corps of Engineers; it is also optionally available in the Federal Specifications, and in ASTM C 150 and AASHO M 85. Although a basis for choosing this limit probably was found in the comparison among structures and what was known of the alkali contents of the cements in them, 0.60 percent is a somewhat arbitrary number. In the present cement shortage in the Southeastern United States it has been questioned in Georgia. The evidence for refusing to raise it to 0.70 consists so far as I know of the existence of alkali-silica reaction in cores from the underpass near Springfield, built with a cement of average alkali content of 0.62 percent with 0.54 percent minimum and 0.73 maximum.[7]

31. It might be possible to decide that cement of not over 0.70 percent total alkali expressed as Na_2O will be allowed in structures other than underpasses that will contain aggregates having service records that demonstrate that they have not been involved in alkali-silica reaction, and to retain the 0.60 percent limit on total alkali where the aggregates to be used are from sources without service records or the structures will be in contact with fill or will be sunk below the general level of the topography. The course just suggested would offer some concession to some cement producers but would be complicated to enforce, and would require investigation of service records of aggregates.

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Table 1

Cores from Bridges in Georgia

Built	Location	Coarse Aggregate Source	Fine Aggregate Source	Cement	Core Location	Condition
1937	4 mi NW of Soperton, Ga.; underpass on Georgia Rt 29	Camak, Ga.	Lumber City, Ga.	J	Vertical core from near top of the wingwall (GDOT-1). Horizontal core from 2 to 3 feet above ground in face of wall parallel to highway (GDOT-2), taken May 1973.	Classified as Class III cracking in 1947.
1937	2 mi N of Springfield, Ga.; underpass on Georgia Rt 21	Camak, Ga.	Eden, Ga.	H	Horizontal cores from about 2 ft above ground on north side of southwest wall (GDOT-4, GDOT-5), taken June 1973	Pattern cracking and larger open cracks in July 1973. Class III, IV.
1946	2 mi S of Millen on Georgia Rt 23; bridge A over Ogeechee River	Camak, Ga.	Eden, Ga.	J	Vertical core in a curb (GDOT-3) taken late May 1973	About Class IV cracking in July 1973.
1947-48	Piney Bluff; US Rt 1 bridge over Altamaha River	Stockbridge, Ga.	Local	J	Horizontal core into north wingwall taken May 1973 (GDOT-6)	At least two open cracks in the exterior face of the core.

Table 2

Composition of Ten Particles of Granite Gneiss from Camak, Georgia*

Particle Number	Plagioclase	Quartz	K-feldspar	Biotite	Chlorite	Kaolin
			Constituents**			
			Reacted particles			
1	1	2	3	4	tr‡	tr+
2	1	2	4	3	--	5
3	2	1	4	3	tr	tr+
4	2	1	4	3	--	tr
5	3	2	1	3	--	tr+
6	2	1	3	4	--	tr
			Unreacted particles			
7	3	2	1	4	--	--
8	1	2	4	3	--	5
9	1	2	4	3	tr	tr
10	1	2	4	3	tr	tr

* From GDOT-2, horizontal core from the underpass near Soperton, Ga., determined by X-ray diffraction.

** In relative order of abundance. All contained a little magnetite.

‡ tr = trace.

Table 3

Condition of Cores

Age	Cement		Core No.	Condition: Cracks in Mortar	Condition: Number of Coarse Aggregate Particles Counted	Condition: With Internal Cracks No.	Condition: With Internal Cracks Percent	Condition: Ettringite	Condition: Gel	
37	J	Underpass near Soperton	GDOT-1*	In top section						
			GDOT-2*	Short	187	44	23.5	Much	Present	
37	H	Underpass near Springfield	GDOT-4*	Few, from	166	33	19.9	Much	Present	Least
			GDOT-5*	outer surface	149	25	16.8	Much	Probable/	
27	J	Bridge near Millen	GDOT-3*	Most	143	42	29.3	Less than 2 previous	Present	Most abundant in these two cores
25-26	J	Bridge near Piney Bluff	GDOT-6**	Present	43	9	20.9	Like the previous	Present	

* Coarse aggregate from Camak

** Coarse aggregate from Stockbridge

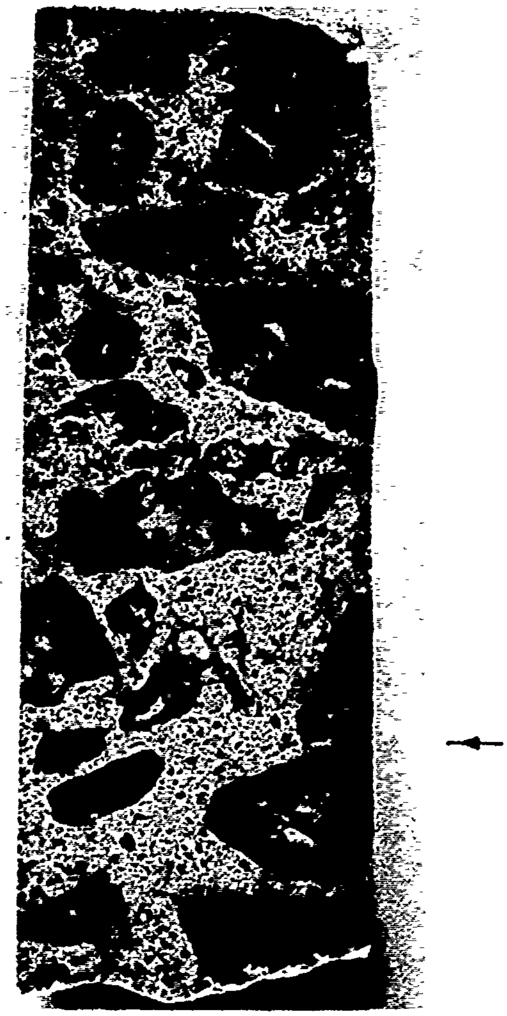
/ In thin section

Table 4

Coarse Aggregate with Internal or Peripheral Cracks, or Both

Core	Nearby Town*	Total Number of Coarse Aggregate Particles	With Internal or Peripheral Cracks, or Both: Number	Percent
GDOT-2	Soperton	187	44	23.5
GDOT-3	Millen	143	42	29.3
GDOT-4	Springfield	166	33	19.8
GDOT-5	Springfield	149	25	16.8
GDOT-6	Piney Bluff	43	9	20.9

* Or locality



GDOT-2(3) sawed and ground surface X 1.1. Top of the core at top. Coarse aggregate particles below arrow and above arrow are internally fractured (see photographs 2,3). Particle near right middle has an associated gel pocket (photograph 4). Many of the pieces of coarse aggregate contain internal cracks.

Photograph 1

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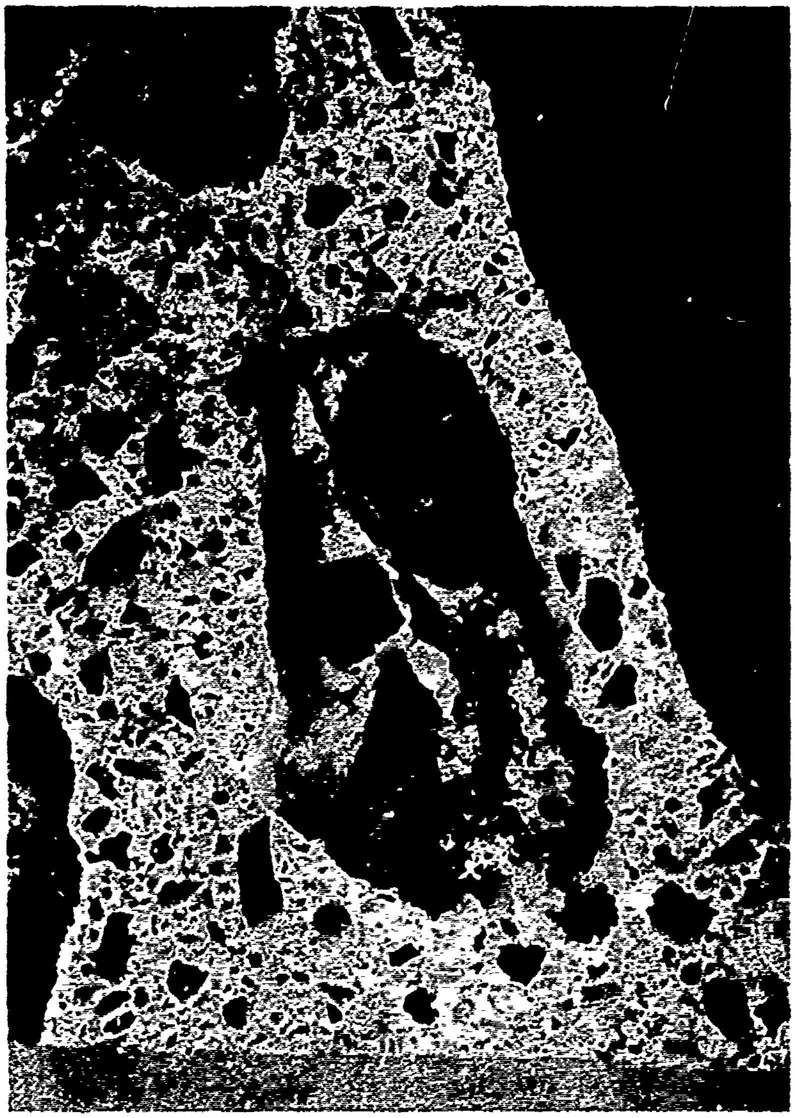
CDOT-2(3) Part of sawed and ground surface X 5.5. Extensive internal cracking of coarse aggregate particle and rim at upper left and lower left.

Photograph 2

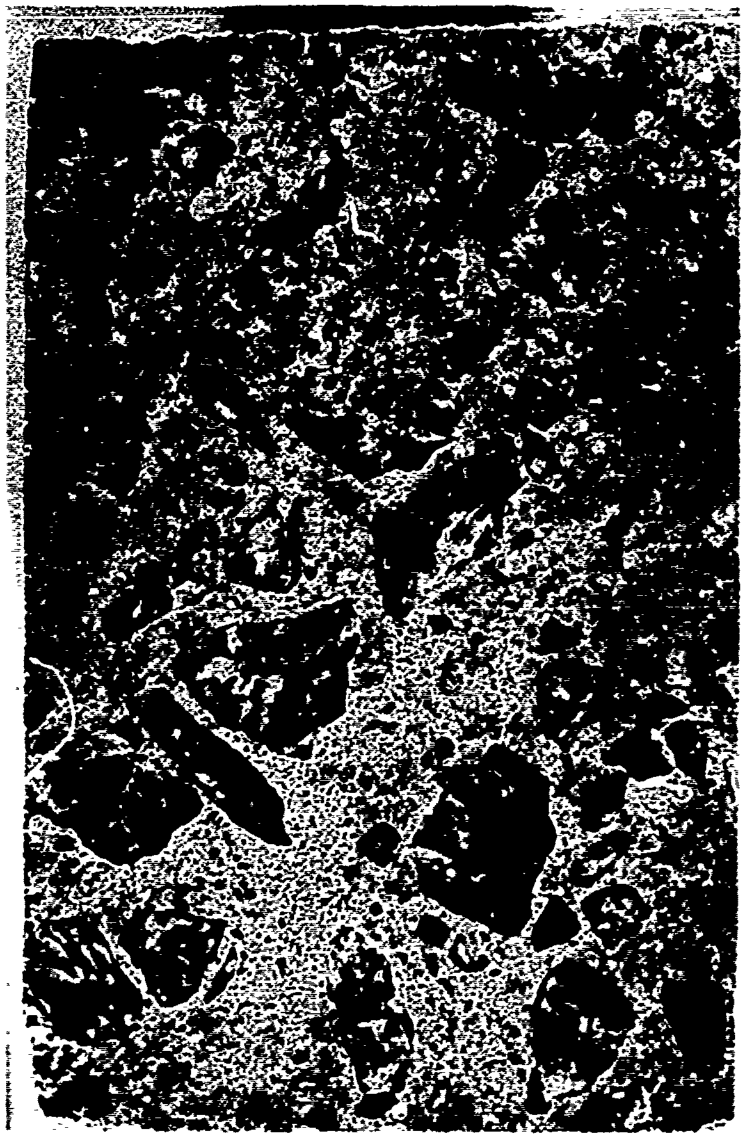


GDOT-2(3) Part of sawed ground surface X 9 showing internal crack in coarse aggregate and apparent rim at top and lower right of particle. Particle in upper left of photograph is shown in photograph 4.

Photograph 3

GDOT-2(3) sawed and ground surface X 9 showing a gel-filled pocket adjoining a coarse aggregate particle with internal cracks.

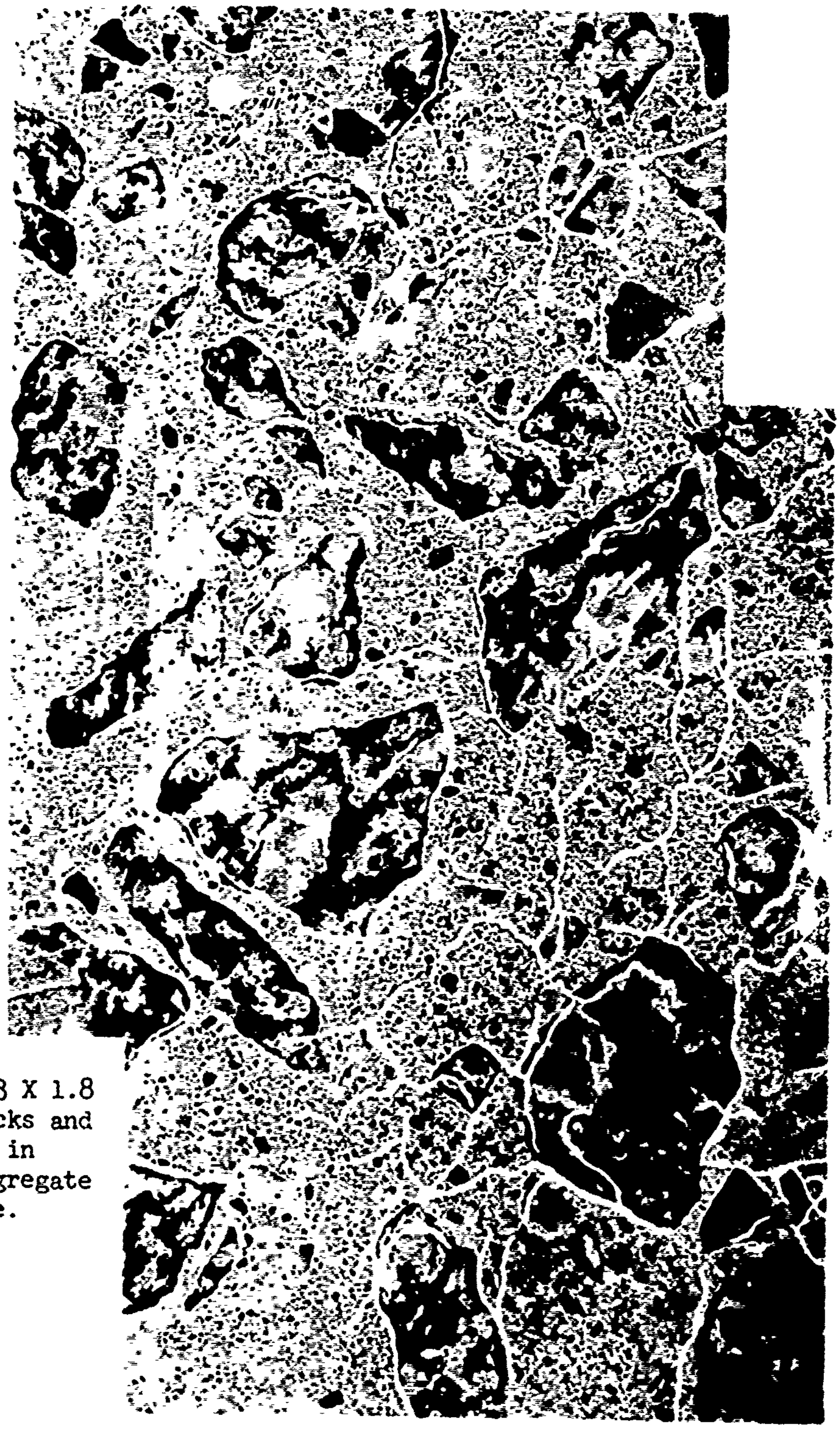
Photograph 4



GDOT-3 Longitudinal sawed and finely ground surface of the upper section of . -ore X 1, showing rimmed coarse aggregate, internally cracked coarse aggregate, and narrow filled cracks in the mortar. The large irregular air void on the right in the lower half is lined with clear gel.

Photograph 5

Top as cast

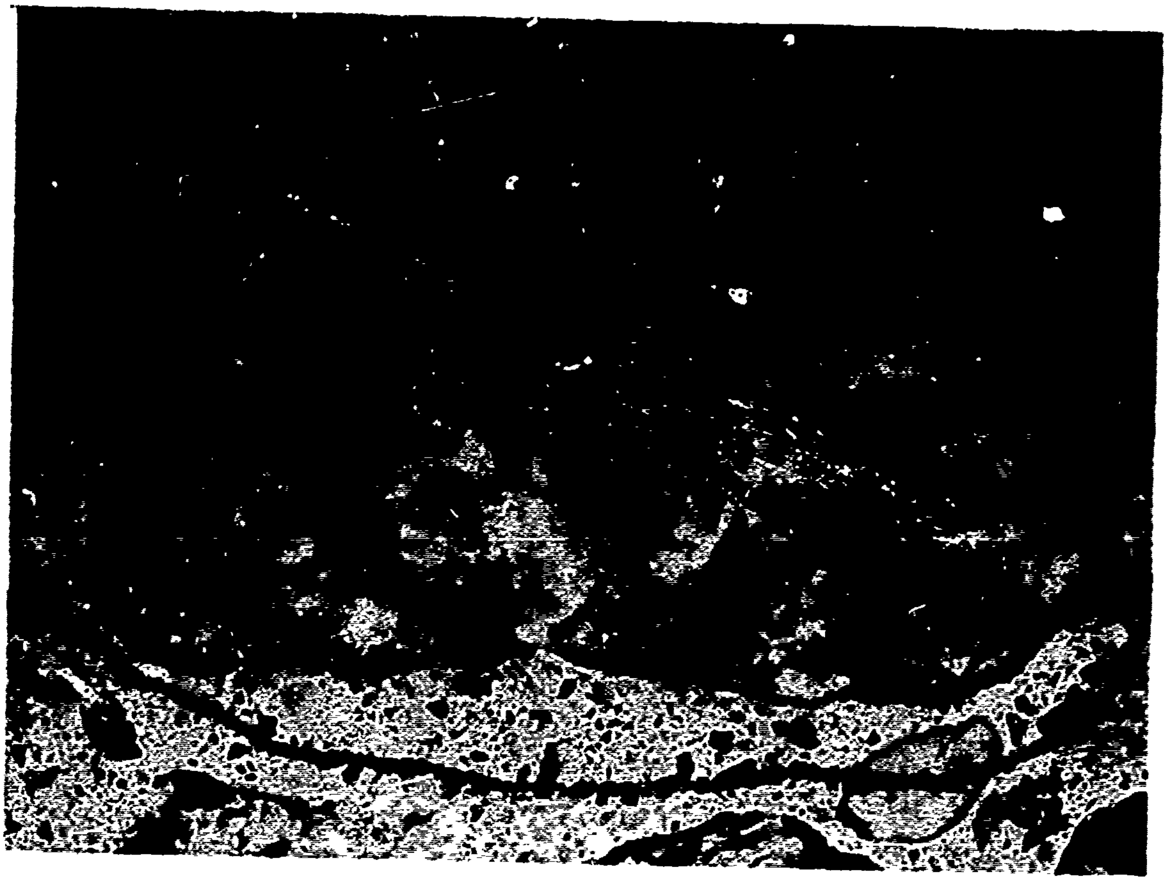


Part of GDOT-3 X 1.8 with open cracks and filled cracks in mortar and aggregate shown in white.

Photograph 6

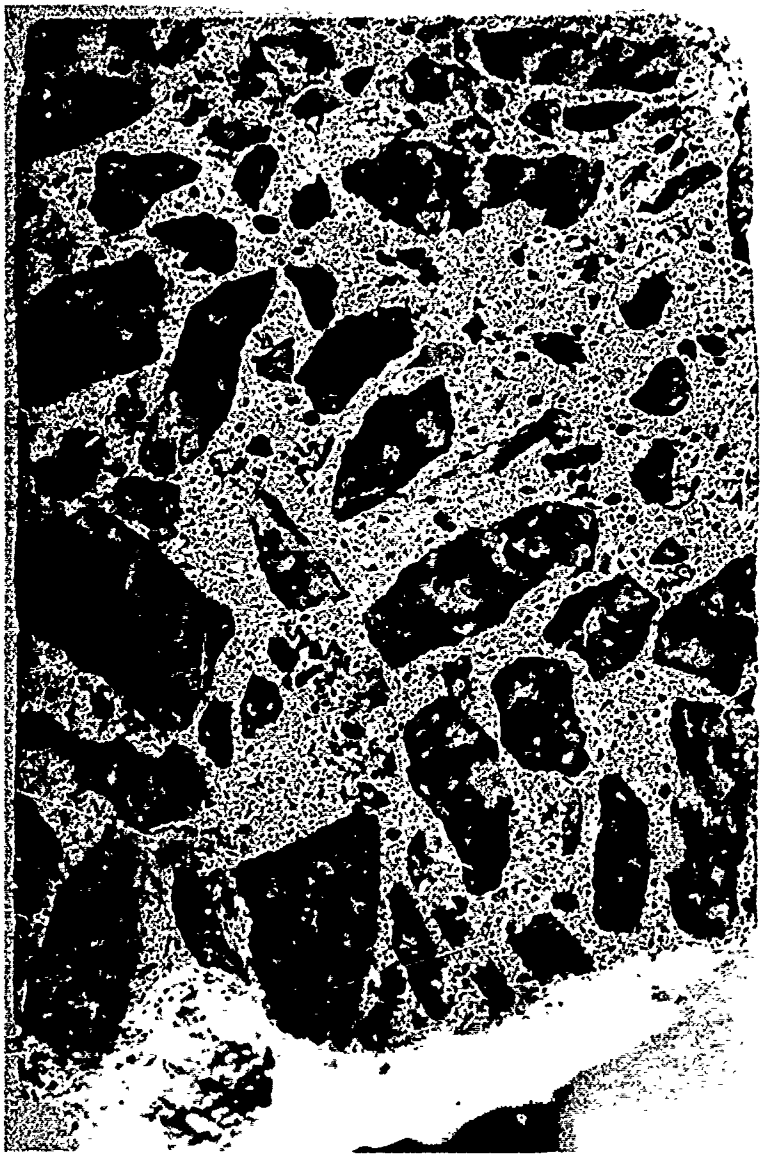
GDOT-4 Springfield transverse slice, finely ground, X 1. Some partial rims are seen, and open internal cracks in the large piece of coarse aggregate near the center at the upper right and the left end of the particle and just to the left of center on the lower margin.

Photograph 7



GDOT-4, from underpass near Springfield, finely ground surface X 3.5 showing rimmed coarse aggregate with some internal cracking including an open crack at the upper left, and several in the fine-grained area in the lower right. This particle is the other half of the cracked particle in photograph 7.

Photograph 8



GDOT-5 (Springfield) finely ground longitudinal slice X 1 showing a crack visible on the outer surface, some rims on coarse aggregate, some internal cracks, and regions of very wet mortar toward lower left.

Photograph 9

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13. ABSTRACT

Six concrete cores from four structures built by the Department of Transportation, State of Georgia, were examined. Two of the structures were built in 1937, one in 1946, and one in 1947-48. Three of the structures were built using high-alkali cement and one with a cement of average alkali content slightly above 0.60 percent. The coarse aggregate in three of the structures was granitic gneiss from one source; the coarse aggregate in the fourth was granitic gneiss from a second source. Evidence of alkali-silica reaction was present in all of the cores in the form of one or more of the following: gel reaction product; internal cracking in some coarse aggregate; and localized depletion of calcium hydroxide in cement paste adjoining some pieces of coarse aggregate. No constituent usually found to be alkali-silica reactive was present. Quartz, which has been associated with alkali-silica reaction on a very few previous occasions, and plagioclase feldspar, appeared to have been the reacting constituents.

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